EGR9020M-PP

Thesis Report

TOPIC: "CYBER PHYSICAL SYSTEM FOR RESILIENCE OF RESIDENCIAL ENERGY CONSUMPTION"

STUDENT:	STUDENT ID:	SUPERVISOR: Dr. Faiz Iqbal

Brainwrites Experts

ABSTRACT

Cyber-Physical Systems (CPSs) are sophisticated systems that result from a combination of elements involved in networking, real-time processing, and physical operations. The resilience of home energy usage has the potential to be significantly impacted by cyber-physical systems (CPSs). CPSs may be used to gather information on energy usage, optimize energy use, give users feedback, and connect with other systems. As a result, homes may consume less energy, spend less money, and be better able to withstand power grid outages. In this study, a cyber-physical system for resilience of residential energy consumption is extensively researched and a framework for system implementation has been proposed. The proposed framework includes three stages: data acquisition, communication network, and data analytics.

The research is carried out based on the narrative literature review method. An overview of the most recent developments in CPSs for the resilience of household energy usage is given in this report. It addresses the difficulties and possibilities presented by this developing topic and offers some suggestions for further research. As a whole, CPSs have the ability to significantly increase the resilience of the domestic energy systems. To overcome the issues with this technology, additional research and development is necessary.

Keywords: Cyber-Physical System, Residential Energy Management, CPS resilience system, Energy consumption management, Smart grids, Smart homes.

BrainwritesExperts

CONTENTS

Brainwrites Experts

LIST OF FIGURES

Brainwrites Experts

CHAPTER 1

1. INTRODUCTION

1.1. BACKGROUND:

Power plays a significant part in our everyday lives. From the beginning of industrialization in the middle of the eighteenth century, our developed and globalized society has depended on a reliable supply of inexpensive energy [1]. The supply of energy affects practically everything that we conduct and encounter in our daily lives, whether it be for production, shipping, or maintenance. It would be hard to move products over long distances, maintain sewers and water pumps, keep food cold in freezers, give online access, etc. without an uninterrupted source of energy. It is possible that our entire civilization might come to an end if the steady energy supply were to be terminated [2].

Coal dominated the power sector throughout the era of industrialization. Steam was created by the combustion of coal, and this steam was then utilized to power up the machines. subsequently, the steam engine's operating theory was adapted for the generation of electricity by employing steam turbines that powered electrical generators. Various sources of fossil fuels, such as natural gas and oil, also came into existence over the years. Large centralized power plants were developed to supply electricity to users linked to a bigger electrical grid in order to take advantage of economies of scale. Carbon dioxide (CO_2) as well as other greenhouse gases are emitted as a consequence of burning fossil fuels, which contributes to the effects of climate change and the increase in global temperatures [3].

1.2. IMPORTANCE OF THE STUDY:

The provision of power, gas, and water are essential assets; when their availability is even temporarily disrupted, civilization cannot operate. As mentioned earlier, downtime causes lost output and fatalities, as well as the possibility of civil upheaval. This is unquestionably true for electricity.

The past couple of decades have seen a severe lack of power due to rapid urbanization. Innovative technologies that are expected to transform how power is generated, handled, and used have

BrainWrites Experts

arrived as a result of the ongoing rise in the consumption of energy in residential settings. Government laws and public awareness compel individuals to switch to renewable energy sources [1].

People are compelled to use renewable energy sources by government regulations and the general public's consciousness. In order to achieve sustainable growth, it is essential to drastically cut the usage of fossil fuels. This is because these fuels are not only prohibitively priced but also extremely polluting. Specifically, the energy sector has been a significant contributor to global warming, generating a sizeable amount (about 38%) of carbon emissions recently [4]. As a result, the electrical sector is progressively undergoing a metamorphosis, evolving from a centralized to a more dispersed network, which necessitates substantial customer involvement.

It is vital to produce enough energy in electric power networks to meet demand in real time. According to the research, in recent years, the conventional approach for handling power networks, which focused mostly on generation, has altered, emphasizing demand-side factors more [5,6]. The power system has been susceptible to load variations with spikes as a result of the outdated practice of disorderly powering up, which is expensive, given that it demands additional transit capacity. Thermostatic loads account for the majority of household loads' peak demand [7], which contributes significantly to grid traffic. Innovative methods for implementing demand-side control depending on commonly referred to as "smart appliances" have emerged as a result of the tremendous advancement in wireless communications and network-controlled system advancements. Smart grids are designed to reduce the challenges of integrating inconsistent power sources and increase the network's flexibility and resilience.

1.3. CYBER-PHYSICAL SYSTEMS (CPS):

CPS is a new class of technology that utilizes cyberspace to combine physical control and inspection across possibly vast regions. It uses hardware, software, and communication networks to keep track of, regulate, and optimize energy use while simultaneously reacting to problems and preserving operational endurance [8]. By reducing the duration of extremely complex operations like bargaining for prices from hours or days to minutes or seconds, these systems offer enhanced efficiency, interoperability, and ease of use in a range of sectors, including smart grid (SG). This scale enables more precise management, leading to gains in efficiency, particularly when it comes

BrainWrites Experts

to energy use. The ***smart grid (SG)*** is one area where CPS is growing [9]. It is a cutting-edge electrical infrastructure that enables two-way communication and energy transfer between customers and suppliers [10].

Numerous studies and programs are looking into the smart grid and its potential for a more proficient, autonomous, and smarter power system [11]. There is a shared pursuit for anything that would permit improved administration and engagement, even though the focuses vary globally, with some initiatives concentrating on the meter systems, others focusing on the essential parts, and some focusing completely on consumers. The rapidly developing telecommunications and information technologies, which have already largely been tested on the web, are now hitting the historically more adaptable energy system, particularly in the form of CPS [12]. The latter is carried out with the intention of addressing complications while concurrently reducing expenses and raising productivity.

Any network or equipment monitoring and regulating resources (such as water and power) in the CPS age is turned smart via embedded complex communication & processing capabilities, ultimately constituting a CPS. A new complex and adaptable network is created by having actuators and sensing devices, alongside the capacity to communicate the determined observations make wise judgments, and take action as a result. Such developing CPS-based networks allow for the delivery of advanced services to various value chain partners as well as consumers, which includes citizens. Since the CPS is designed to become a transportation infrastructure for gas, water, or electricity that can exhibit self-x behavior [13], such as managing oneself, self-awareness, self-optimization, self-regulatory self-healer, self-protection, etc., it is anticipated that the electrical system will reap benefits immensely in the long run.

Since power progressively assumes the function of the most significant energy carrier in a decarbonizing world, the growth and effects of CPS on the power area (usually referred to as yet not restricted to Smart Grids) are of the utmost significance [14]. Additionally, compared to either gas or water, electricity is simpler for people to produce and feed back into the grid, which is a driving force behind the creation and uptake of smart grid and CPS-enabled systems.

Many studies, businesses, and government agencies are looking at how involving communities in load distribution might help prevent power outages and load shedding. To avoid interruptions for consumers, demand as well as supply can be adjusted, for instance by conserving energy, time-of-

BrainWrites Experts

use price, and controlling the functioning of electricity-intensive products [15]. Similarly, expanded access to power and the electrification of industries that presently rely on alternative sources of energy are predicted to cause a 50% rise in worldwide power consumption by 2040. Our dependence on energy is growing as a result of digitization since it powers the data centers, networks, and gadgets that enable digital interaction, home automation systems, online banking, and a great deal more. As a result, the danger of power cutbacks and breakdowns is rising, and the globe is growing reliant on reliable access to power [15].

In order to guarantee the reliability and continuity of electrical power in household environments, this research will focus on a cyber-physical system (CPS) for the resilience of residential energy consumption (REUC). In general, CPS may be applied in a variety of ways to increase the electrical consumption of homes' resilience. CPS can be used, for instance, to [16]:

- Real-time monitoring and management of consumption of energy enables more effective use of power.
- Detection and response to grid disruptions, such as power spikes or outages, are also possible.
- Give feedback to homeowners on the amount of energy they consume, assisting them in reducing their usage.
- Manage the use of dispersed power sources, including solar panels and batteries.

1.4. AIMS AND OBJECTIVES:

The aim of the study is to research using a cyber-physical system to increase the resilience of household energy use.

The research's particular objectives are to:

- To study the current level of home energy use and the risks and challenges that affect resilience
- To recognize the most recent developments in CPSs for household energy use
- To study the effects on power productivity and durability of incorporating sensors, smart meters, and data analytics

BrainWrites Experts

- To determine the obstacles to and possibilities presented by employing CPSs to increase the energy consumption of homes.
- To analyze how energy storage devices may enhance resilience and offer backup power during outages
- To analyze the user engagement tactics and behavioral adjustments required to encourage homes to be resilient and energy-efficient
- To analyze the effects of establishing a CPS for residential regions on the economy, environment, and society
- To create a plan for how CPSs will be implemented to reduce home energy use.

1.5. OVERVIEW OF THE REPORT:

The dissertation will present a review of previously published work regarding the way to manage household energy and move towards renewable energy consumption through physical systems. This report is made up of five chapters that cover relevant topics such as the literature review, methodology, results, discussion, conclusion, and recommendation. The following potential developments might be incorporated into this project:

- Chapter 2: The literature review analyzes the body of work published earlier. It highlights the most important conclusions from prior studies and points out any discrepancies in the literature
- Chapter 3: The research methodology is covered in this section. It contains details on the study's strategy, the data gathering techniques, and the data analysis techniques. Along with this it also sheds light on implementation and testing.
- Chapter 4: The study's results are presented in this section and are being discussed with respect to the pros and cons. It is organized clearly and succinctly and backed up with facts that serve as support.
- Chapter 5: The key findings of the study are outlined in the conclusion, along with the recommendations.

BrainWrites Experts

<u>**CHAPTER 2**</u>

2. LITERATURE REVIEW

The subsequent sections provide detailed research findings regarding cyber-physical systems, especially in the context of the resilience of residential energy consumption.

2.1. CYBER-PHYSICAL SYSTEMS:

2.1.1 TRENDS AND HISTORICAL CONTEXT

Helen Gill of the US National Science Foundation first used the idea of a "Cyber-Physical System" (CPS) in 2006 [17]. However, history also noted that CPS evolved from earlier ideas like mechatronics, system integration, ubiquitous computing, cybernetics, and others. The National Science Foundation (NSF) Workshop on Cyber-Physical Systems in October 2006 [18], the workshop "Network Embedded Control for Cyber-Physical Systems" in November 2007 [19], the report by President's Council of Advisors on Science and Technology (PCAST) highlighting CPS as a national research and development priority in 2007 [20], and the NSF call for proposals for CPS research in 2008 were important initial events.

According to [21], Google Scholar results on searches for the phrases "cyber-physical system" or "cyber-physical systems" are displayed in Figure 1 below. The findings show that there were 35 papers published in 2006 and over 1,000 publications in 2017.

BrainWrites Experts

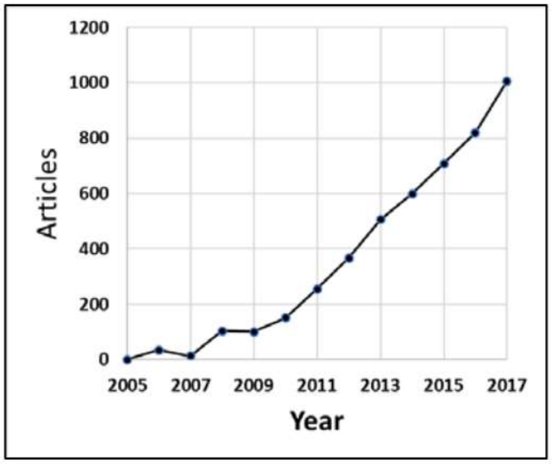

Figure 1 Articles on Cyber-Physical System Trend

Figure 2 displays the findings of a Google Trends investigation of "cyber-physical systems" search queries throughout the world. As evidenced by Google searches, these findings also demonstrate a consistent rise in curiosity regarding CPS from January 2005 to May 2018 [21].

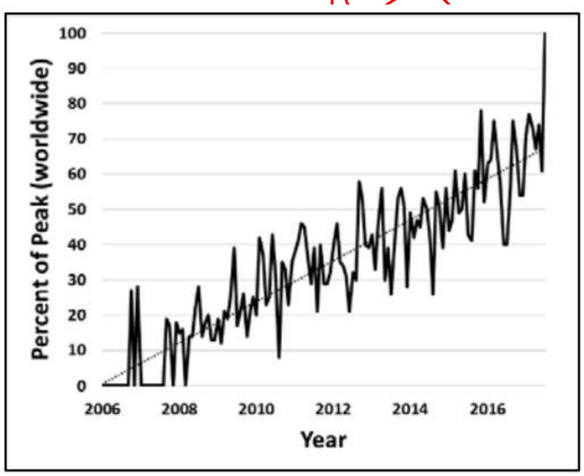

Figure 2 Query Trends related to CPS

The trend patterns in CPS research publications and search queries support a subject that is experiencing constant progress with no signs of development slowing down.

2.1.2 WHAT IS A CYBER PHYSICAL SYSTEM (CPS)?

In light of its extensive effects on society as a whole, the economy, and ecosystems, studies regarding cyber-physical systems (CPS) are currently attracting the interest of the academic community, business, and authorities. This technology will serve as the cornerstone of vital infrastructure and enhance many aspects of the standard of life. Globally, CPSs have the ability to have an influence on a number of economic regions.

Cyber-physical systems are frequently regarded as the next wave of design systems that integrate communication, computing, and management to meet the objectives of rigidity, efficiency, resilience, and productivity of physical systems, despite the absence of a precise description [5].

As mentioned in [17], CPS is essentially an engineering profession that focuses on technology and mathematical concepts to represent physical phenomena (differential equations, stochastic processes, etc.). In a CPS, computational components work together and interact with sensors, which keep an eye on cyber and physical sensors and actuators. Due to their shared fundamental design, CPS and the Internet of Things (IoT) are similarly comparable.

In the words of Helal et al. [22], CPSs are complicated structures that integrate 3C technologies (computation, communication, and control). They integrate physical features (sensors and actuators) with cyber abilities (computation and communication). Nearly everything uses CPS, such as construction structures, manufacturing plants, vehicles, electrical supply networks, and municipal facilities.

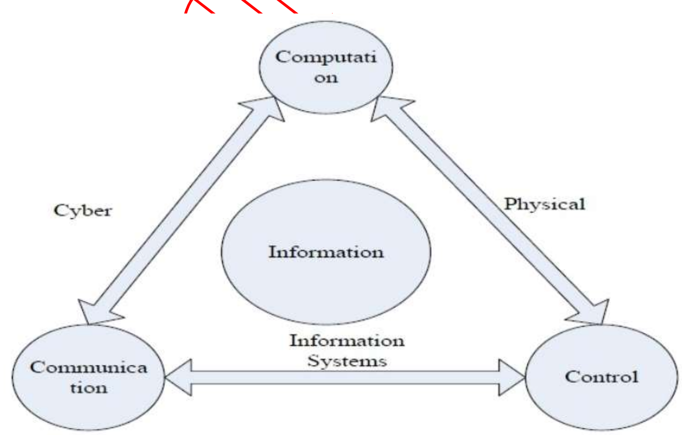

Figure 3 3C Concept of CPS

A CPS is composed of three main components: a physical system, a networking and communication component, and a distributed cyber system. The development of CPSs uses a variety of components of various hardware, software, and networks that are integrated into real-

BrainsitesExperts

world surroundings and processes. The software, which contains all software programs for analyzing, filtering, and keeping information, plays the most crucial part. CPSs communicate across the network with the physical systems [2].

2.1.3 WHAT IS RESILIENCE?

In general, the ability and constant process of resiliently enduring difficulties and strain while retaining adequate functioning is known as resilience [23]. Diverse fields have investigated the idea of resilience using different perspectives. In order to grasp and define home energy resilience, this report is drawing on already-existing resilience research in domains relevant to domestic energy usage. A resilience paradigm for power systems was established by Hamborg and colleagues, wherein resilience is defined as a thing carrying an objective. In other words, resilience is the endurance or accomplishment of a purpose in the presence of disruptions [24].

A resilient power system constitutes a system in which energy contributes as effectively as possible to the economic, ecological, and social growth of a nation, possesses the capacity to endure shocks and bounce back swiftly, and takes into account the potential effects of changes in the climate on energy supplies in its establishment and functioning [25]. It has the following aspects, including:

- The security of electricity enables the *consistent energy* required for economic growth.
- Renewable energy's affordability *lowers the price* of power, heating, cooling, and transportation while raising overall *energy effectiveness* [26].
- Sustainable development in the atmosphere *reduces carbon footprints* along the whole power supply chain.
- A robust power system will maintain the three facets of resilience in equilibrium; placing too much emphasis on one at the cost of the others is almost always suboptimal.

The figure below depicts a resilient energy system [25]:

Brainwrites Experts

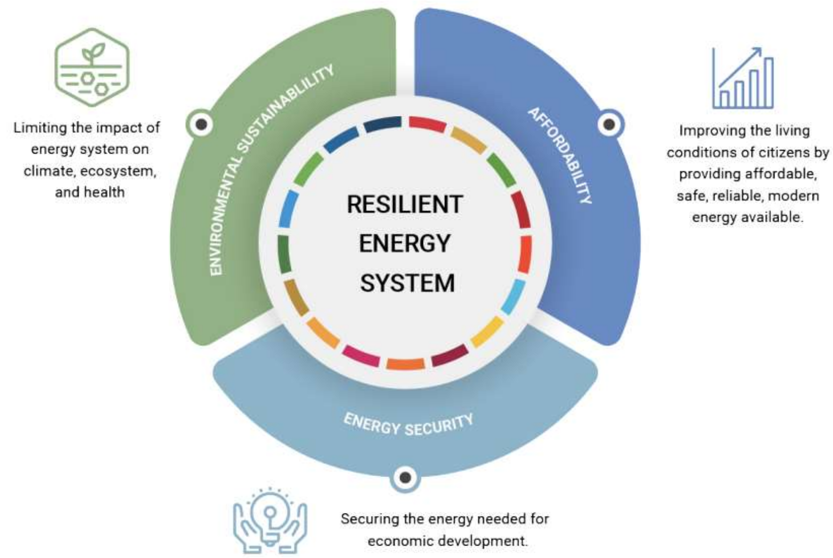

Figure 4 Resilient Energy System

A community's resilience plays a key role in guaranteeing the safety and wellness of its residents as well as how they handle power outages. The electrical system or power grid is regarded as the resilience unit in a large body of power-related resilience investigation, and its primary purpose to retain is the supply of power [27]. Energy regulation also places a high priority on building a durable infrastructure for energy and guaranteeing a steady supply [15].

2.2 REVIEW OF RELATED SIGNIFICANT PUBLICATIONS:

The following is a summary of the literature that highlights some significant studies and publications on cyber-physical systems for resilience of home energy consumption:

The study conducted by Franco et al. concentrates on the incorporation of renewable energy sources and storage of energy, and they provide a cyber-physical system (CPS) for household power control [28]. The framework intends to promote the usage of clean energy, reduce energy utilization, and boost the overall sustainability of household energy systems. The CPS architecture used in the article consists of a number of parts, such as smart meters, household power management systems (HEMS), systems for storing electricity (such as batteries), and sources of clean energy (such as solar systems). The wireless sensor network that connects these parts and allows them to exchange information allows for real-time tracking and management of the

BrainWrites Experts

production of energy and utilization. The incorporation of response-to-demand tactics into the CPS is also covered by the researchers. Residents can alter their ways of energy consumption in accordance with pricing or grid indicators by participating in demand response programs, which helps to stabilize the system and lower peak demand [28].

Another article on how to optimize energy usage in household microgrids using cyber-physical systems (CPS) is provided by Karthikeyan [10]. The research states that energy utilization in home microgrids may be optimized using cyber-physical systems (CPS). It is found that CPS may gather information from a variety of sources and utilize it to optimize consumption of energy. According to the article, CPS has the potential to cut energy use by as much as 20%. This concludes that CPS possesses the capability to transform home microgrid energy management [10]. The paper presented a way for good energy management by splitting a four-layered management approach into generation, consumption, storage, and sharing. All household appliances, including air conditioners, refrigerators, fans, and lights, were taken into account when calculating usage. In the generation section, renewable energy sources including solar PV panels, wind energy, and fuel cells were used.

When there is surplus energy produced, the lead acid battery is taken into consideration for energy storage. Instead of using the extra energy produced by renewable sources during the low demand time, the extra power is permitted to be shared in the microgrid. The Smart Cyber Physical Controller (SCPC) receives the overall power value from the Smart Energy Monitor Unit (SEMU), that tracks the amount of energy and consumption of all gadgets in the house. Concerning the priority levels, the SCPC analyses the consumption profiles of each separated appliance and examines the power value from the SEMU [10]. The pictorial representation of the system is shown in the figure below [10]:

BrainWrites Experts

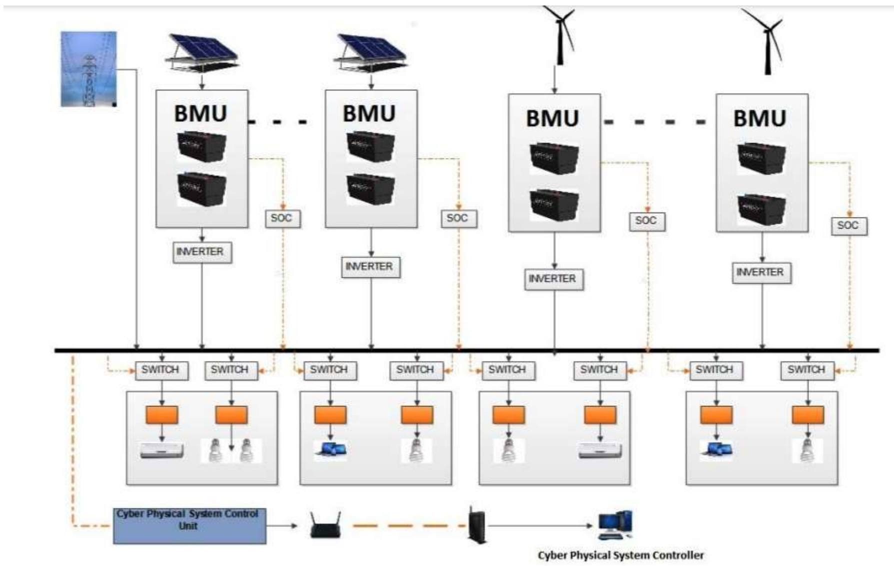

Figure 5 Microgrid System

The generating system tracks renewable energy production; smart meters connected to the system track the power from solar and wind sources and send the information to the SCPC system. The data is collected by the SCPC unit and compared to the load profile data from the SEMU. Based on the weather, the SCPC unit also predicts the load and generation. The block diagram of the home energy management system is shown below [10]:

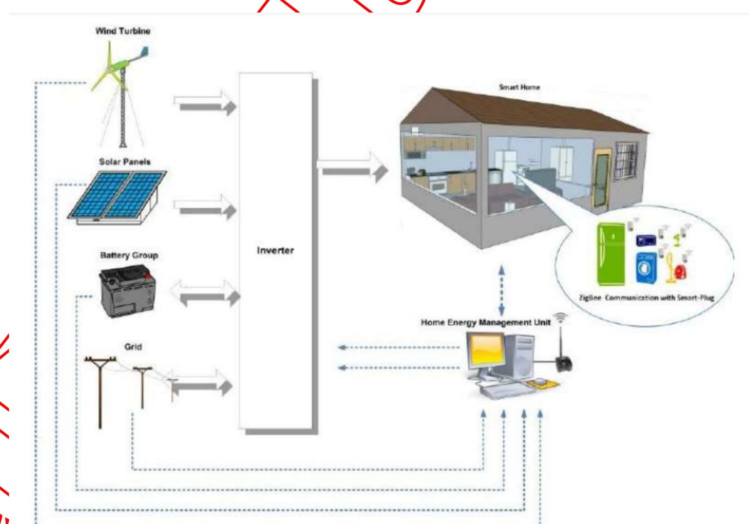

Figure 6 Home Energy Management System

For the sake of economic growth and financial stability, cheap, secure, and dependable electricity must be made available. The power system is vulnerable to a variety of natural, man-made, and technological challenges, which might result in anything from blackouts to a persistent energy shortage [29]. By anticipating future demands and making investments in durable electricity systems, politicians, administrators, and operators may protect their power networks from these dangers. A thorough discussion has been made on the threats to cyberphysical systems which can be seen in the subsequent paragraphs.

Critical infrastructure (CI) areas including the smart grid, medical care, the armed forces, and telecommunication are experiencing a fast evolution of cyber-physical systems (CPSes). Given the opponents' innovative attack strategies and techniques, contrary to the advantages of CPS, these systems are always in danger from malware assaults. In the context of creating robust cyber-physical systems (CPS), M. Imran Malik et al. [8] presents a thorough analysis of contemporary malware detection techniques in his paper. The study's main objectives are to comprehend recent developments in malware detection, uncover current shortcomings, and suggest new routes for improving CPS resistance to malware assaults.

The researcher discusses numerous methods for detecting spyware, such as behavior-based, anomaly-based, and signature-based methods. To recognize and reduce malware risks, these approaches make use of various techniques including matching patterns, machine learning algorithms, and dynamic analysis. The study further outlines the benefits and drawbacks of current methods, points out any flaws in them, and suggests new avenues for improving the safety and versatility of CPS against malware assaults [8].

Another research done by Ghiasi et al. [30], examines the subject of cyber-physical security in smart power systems with an emphasis on robustness and the presentation of ideas and potential remedies. In order to maintain the resilience of smart power systems, it analyses the difficulties presented by the pairing of physical and digital elements in electrical networks and highlights the demand for strong security precautions. In the context of cyber threats and assaults, the paper emphasizes the significance of resilience in assuring the ongoing functionality and operation of smart power systems. In order to lessen the effects of cyber catastrophes, the researchers examine the qualities and elements of secure power systems. The study emphasizes the necessity of

BrainWritesExperts

collaborating and exchanging information in order to create efficient security plans and guarantee the resilience of the power system.

In order to increase the effectiveness and robustness of household energy use, the paper presented by de Castro Tomé et al. [31] suggests a cyber-physical residential energy management system (CPEM) that makes use of virtualized packets. There are three primary parts to the CPEM:

- A residential energy router (RER) is in charge of gathering information from household appliances and gadgets as well as communicating control orders to such appliances and devices.
- A virtualized packet (VP) server is in charge of controlling the VPs that are employed for communication among the RER and the home's gadgets and appliances.
- A mechanism for decision-making that is in charge of deciding how to distribute the home's energy resources.

The figure below displays the system architecture:

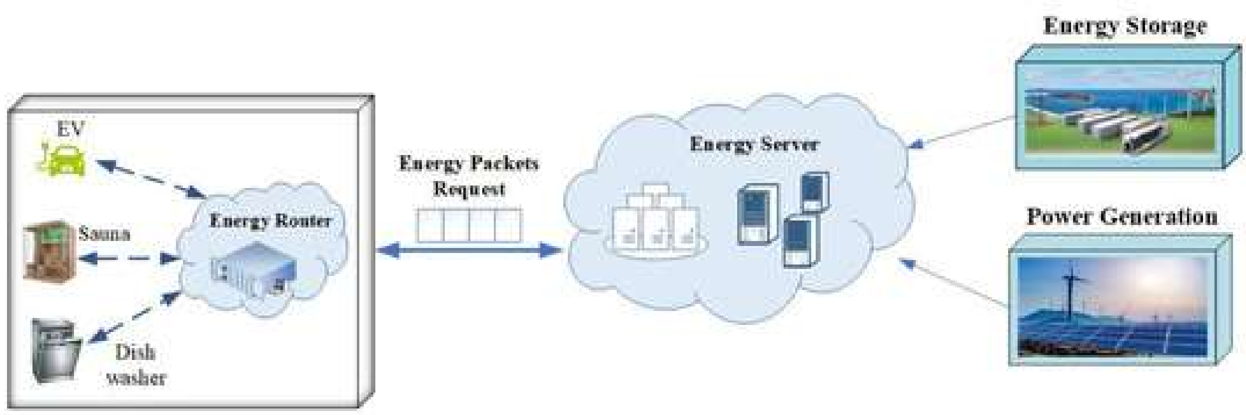

Figure 7 System Architecture

The paper [31] defines the following ways that the CPEM uses VPs to raise the effectiveness and resilience of home energy consumption:

- To communicate with household appliances and other devices more effectively than conventional communication channels.

Braille Experts

- The RER and the home's appliances and equipment may communicate with one another more reliably by using VPs.
- For distributing energy resources in the house, more complex decision-making algorithms may be implemented using VPs.

Another research work done by Orumwense [32], discusses issues associated with home energy management, such as the requirement to cut energy use, increase effectiveness, and guarantee grid resilience in his article. The usage of CPS in addressing these issues is then explored. The paper identifies the ways to use the CPS system, for instance for real-time monitoring and management of energy use enables more effective use of the resource. To identify grid abnormalities, such as surges or power outages, and take appropriate action. To utilize dispersed energy sources, such as solar cells and batteries, in concert and give locals feedback on their energy use in order to encourage them to use less.

The article [32] goes on to detail CPS's plans for domestic energy management in the future. It indicates that the following areas should be the focus of future research:

- The creation of communication networks that are more dependable and secure
- The creation of timely and more precise energy usage statistics
- The creation of more user-friendly user interfaces so that locals may communicate with the system

The concept of energy resilience in communities offered by Abi Ghanem and associates [33] outlines how tolerance, conservation, adaptation, and change might be carried out in the setting of everyday life: Transforming the functioning of practices by altering physical components, learning what to do when an electrical failure occurs, and adopting new definitions to accomplishing ease, practicality, and cleanliness" are some examples of how resilience may be described and understood. In this perspective, altering how daily activities are carried out is crucial, and these modifications include the use of new materials, information, and understanding of new meanings [33].

The research shows that a well-liked method of handling, storing, and analyzing data in energy systems is cloud computing. It provides a scalable, upon request, and economical strategy for

BrainWrites Experts

distributing IT resources through the Internet, as stated by [34]. A number of scholars have looked at how cloud computing might be used to manage and optimize energy use. In [35], the authors evaluate how cloud computing might handle the additional problems that smart grid technology offers for thorough data management. They investigated the application of cloud computing in a number of areas, including the administration of energy, demand-side management, property energy management, power hubs, and power-delivering systems. Their investigation covered smart grid and energy management techniques.

The reference [36] discusses demand-side management strategies for smart grids, highlighting the value of load estimation, demand response strategies, and storage of electricity for attaining grid stability and conserving energy. Optimizing the effectiveness of energy management systems through cloud computing and Internet of Things (IoT) integration has enormous promise. IoT offers a platform for integrating and gathering data from numerous detectors and components, and cloud computing makes it possible to handle and analyze this data.

While considering challenges, the main obstacles to CPS construction, implementation, and innovation can be broken down into three categories: technological, educational, and regulatory obstacles.

Technical Difficulties:

The unique characteristics of CPS in contrast to traditional networks are a contributing factor to the technological problems. To ensure the integrity, confidentiality, reliability, and cybersecurity of CPS, for instance, distributed, interconnected, independent, and dependable systems must be developed [12].

Over a decade ago, businesses began to produce interconnected systems with an appropriate amount of flexibility and adaptability that could be merged and coupled with previous ones, but installation, evaluation, and verification are still in their infancy. The primary obstacles to the deployment of autonomous systems in various industries continue to be worries about safety and dependability [37]. A further technological difficulty that needs to be appropriately handled is the creation of multiple methods for preserving the confidentiality of the data given the amount of information that will ultimately be produced, acquired, and handled by CPS [12].

Educational Obstacles:

BrainWrites Experts

According to [38], the shortage of experienced workers, knowledgeable individuals, specialists, and academic instructors with an extensive understanding of CPS is projected to continue to be a significant obstacle to the advancement, creativity, and deployment of CPS for no less than over the next ten years. This is mostly because the discipline of CPS necessitates the incorporation of skills from numerous engineering fields, including computer science, computational engineering, civil, mechanical, or electronic engineering, and systems design with the proper combination of both research and practice. The complexity of knowledge needed for CPS development and evolution makes this field's education difficult. As a result, new educational and training systems ought to be developed.

Another challenge to providing the necessary training and instruction in the area of CPS is the absence of cyber-physical labs and testing facilities in educational settings and enterprises. To acquire the necessary programming, training, and experimentation skills, those working in the arena of CPS require accessibility to testbeds with varying degrees of functionality and integration of physical and cyber components [39].

Legal Obstacles

Various rules and policies pertaining to privacy of information, network and customer safety, responsibility, and CPS evaluation and accreditation are required due to the utilization of CPS in various industries. Novel legal rules and terminologies might also be required to expressly suit the prerequisites of CPS given that it could encompass multiple states, districts, or even continents [40].

BrainWrites Experts

CHAPTER 3

3. METHODOLOGY

A narrative literature review approach has been utilized in this report. In this methodological approach, a descriptive and qualitative synthesis of the body of literature on a particular subject is provided [33]. The main conclusions, themes, and trends from the examined papers are summarized and synthesized to provide a cogent narrative or tale.

3.1 NARRATIVE REVIEW APPROACH:

Unsystematic narrative reviews, often referred to as narrative overviews, are thorough narrative synthesizes of previously published articles. Such a study of the literature outlines the researcher's discoveries in a concise manner. It generally sums up each publication's material. Some academics argue that a thorough narrative summary ought to evaluate each of the relevant studies, but other writers claim that it is not necessary [41].

According to [33], a complete, critical, and impartial examination of the most recent research on a subject constitutes a narrative literature review. It is a particular kind of literature review that lacks a methodical or organized methodology. Instead, it enables the writer to create a more comprehensive and narrative synthesis of the literature.

In other words, by emphasizing the narrative or story-like representation of the literature as opposed to the statistical examination or quantitative information, the narrative literature evaluation technique varies from other forms of literature reviews, which include systematic reviews or meta-analyses. The narrative method provides for a more adjustable and personal assessment of the literature rather than employing a predetermined set of standards to choose and evaluate research [42].

There are several benefits to crafting a strong narrative summary. Since they combine several bits of knowledge into a legible style, instructive materials benefit greatly from narrative summaries. They are helpful in giving a thorough understanding of a subject and frequently include historical details on the development or resolution of a problem. Since they offer students just one place to learn from, are frequently more up-to-date than textbooks, and introduce them to literature that has been reviewed, narrative overviews are popular among professors to utilize in the classroom [33].

BrainWrites Experts

A research question or area of interest is first chosen in this narrative literature review. Then databases, libraries, and other sources to look for related material are utilized. Studies are chosen based on their applicability to the research issue, as well as the caliber of their methodology, conclusions, and theoretical underpinnings. The research is done by reviewing and summarizing each study, locating significant insights and recurring themes, and arranging the data in a comprehensible and logical way.

The structure of the report based on a narrative approach is followed as mentioned below:

- Research questions have been created to frame the literature review of the given topic:
- A thorough search of the literature to find relevant works that are connected to the research issue has been performed. Search engines, academic databases, and other pertinent sources are all to be used.
- Inclusion and exclusion criteria for the selection of articles to determine which ones are pertinent to the research issue have been done.
- Work is in progress to extract pertinent data from the chosen papers, including the main conclusions, the methodology employed, and other pertinent information.
- Identification of any gaps or inconsistencies in the literature as well as parallels and differences across the studies will be performed.
- Discussion and Interpretation of the results' implications, the studies' advantages and disadvantages, and future suggestions for further studies will be provided.
- At the end of the report, a summary of the key findings and recommendations from the narrative review in conclusion will be presented.

3.2 DATA COLLECTION, IT'S VALIDITY AND RELIABILITY:

Terms like validity and reliability serve to assess the caliber of research [43]. Several actions were taken to make sure the study was reliable and valid. First and foremost, to reduce any potential biases, a meticulous selection of publications was made. To guarantee that the research was based on accepted ideas and earlier research findings, a thorough literature analysis was carried out. Expanding on prior information, supported the validity of the research.

BrainWrites Experts

The validity and dependability of the study conclusions are directly impacted by the standard and correctness of the data collected. In order to maintain the integrity of their study, researchers might use a variety of methodologies and procedures for data collection [44].

In conclusion, it is essential to take into account a variety of variables while evaluating the validity and reliability of research. By doing this, one may increase your level of assurance that the outcomes are reliable and suitable for use in making judgments. The standard of the sources that are studied will determine the validity and dependability of the study in a narrative literature review. Peer-reviewed literature from recognized publications should be used. The data gathered for this report is from books issued by respected publishers, academic conferences, and peer-reviewed journals. Apart from this the data gathered are all recent and have adequate information that applies to the chosen topic.

3.3 DESIGN

A cyber-physical system (CPS) for household energy resilience integrates the physical and cyber components of a system to improve its resilience to disruptions [45]. In developing the framework, the following basic aspects would need to be taken into consideration:

- **Physical components:** Appliances, the electrical grid, and energy storage systems are the physical components of a household energy system. Interconnections and communication between these components would need to be ensured when building a framework
- **Cyber components:** The sensors, controls, and software make up a household energy system's cyber components. These components would need to be safe and able to survive cyberattacks [45].
- **Data and analytics:** The framework would need to gather data from the system's physical and digital components and utilize it to assess the system's functionality and spot any possible dangers.
- **Making decisions:** The framework would need to be able to choose how to run the system to reduce interruptions and increase resilience.

The framework proposed for household energy resilience is discussed in the subsequent section.

Brainwrites Experts

3.3.1 PROPOSED FRAMEWORK

Perception, transmission, and application are the three levels at which CPS functions, also shown in Figure 8 [46].

Perception Layer:

A cyber-physical system's (CPS) initial layer is the perception layer. Its job is to gather input from the physical environment and translate it into a form that the CPS's other layers can comprehend. Sensors, actuators, and other tools that may gather data from the physical world often make up the perception layer [47].

The perception layer's sensors are in charge of gathering information about the outside environment. Any physical quantity, including sound, light, temperature, and pressure, can be used to represent this data. Based on the information gathered by the sensors, the actuators at the perception layer are in charge of taking appropriate action. For instance, a motor or valve might be moved by an actuator [48].

Transmission layer:

Among the application and the perception, data is exchanged and processed at the transmission layer (also known as the network layer). Local area networks, the Internet, or communication technologies like Wi-Fi, Bluetooth, ZigBee, and infrared are used to transmit data [49].

A cyber-physical system's (CPS) second layer is the transmission layer. It is in charge of transferring information between the application layer and the perception layer. LANs, the internet, cellphone networks, and other communication networks are frequently used by the transmission layer. The following duties fall under the responsibility of the transmission layer:

- **Data encapsulation:** To enable the transmission of the data through the communication network, the data from the perception layer is packaged into packets.
- **Routing:** The packets are sent to the target node through the communication network.
- **Error detection and correction:** During data transmission, errors must be found and fixed by the transmission layer.

BrainWrites Experts

- **Data flow management:** To prevent congestion, the transmission layer is in charge of managing the data flow between the sender and the receiver.

CPS must include the transmission layer since it is in charge of guaranteeing the timely and reliable transfer of data from the perception layer to the application layer.

Application layer – Cyber Level:

The third and top layer of a cyber-physical system (CPS) is the application layer. It is in charge of analyzing the transmission layer's data and choosing how to communicate with the physical world. Typically, software that can analyze data and make judgments makes up the application layer [50].

The following duties fall under the purview of the application layer:

- **Data interpretation:** The application layer interprets the transmission layer's data. Making sense of the data entails figuring out its patterns and trends.
- **Making decisions:** Using the interpreted data, the application layer decides how to communicate with the physical environment. This might entail managing the actuators, planning the system's functioning, or giving users advice.
- **Feedback to the user:** The application layer informs the user of the system's status and the choices that have been made. The user can utilize this input to modify the system or enhance the system's functionality.

The application layer is important for the CPS system since it is in charge of giving the system intelligence and controlling how it communicates with the outside environment.

BrainWrites Experts

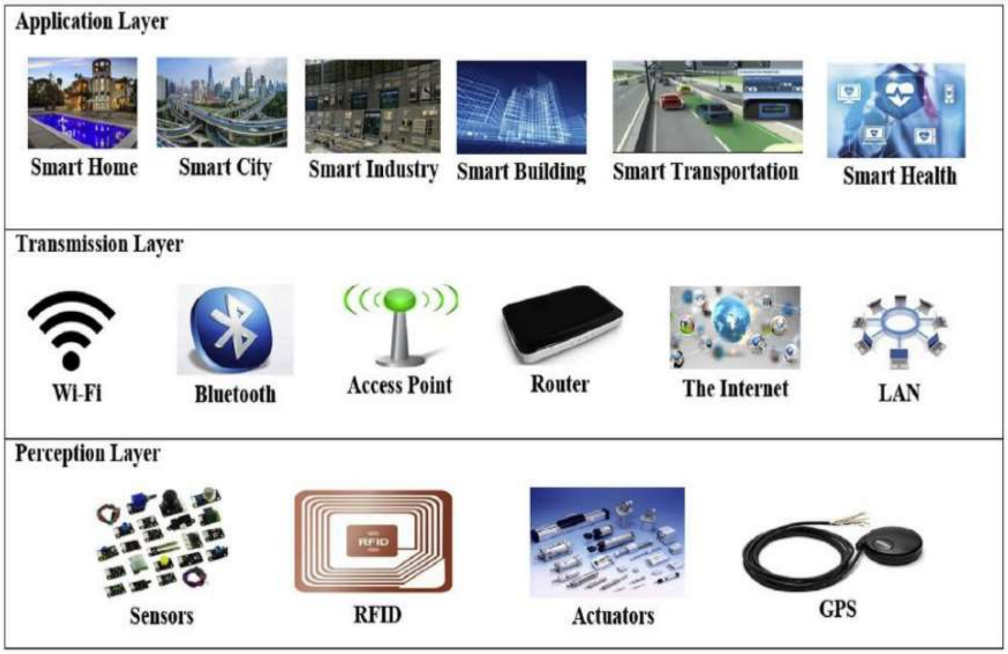

Figure 8 CPS architecture layers

3.3.1.1 CPS FRAMEWORK FOR RESIDENTIAL ENERGY MANAGEMENT SYSTEM:

The article [28] is taken as the base for the development of the CPS home energy management framework.

The residential energy management is divided into three primary stages, which are represented in Figure 9, Data Acquisition, Communication Network, and Data Analytics. Appliances and metering equipment are both part of the first step. The Communication Network Layer, which is one step above, enables data interchange between the sensing devices and a server. Using short-range communication technologies like WiFi, ZigBee, or others, data is transmitted within the home area network [51].

Following that, the data is sent to the upper Data Analytics Layer using long-distance communication technologies like 5G, enabling data transmission between physical devices and middleware technologies where Data Analytics processing is hosted (i.e., providing connectivity through the WAN). In order to integrate and coordinate the nodes and administer the home in real-time, middleware solutions are employed [52].

Brainwrites Experts

The data is managed, monitored, and analyzed (including comfort-level analysis, forecasting, and other functions) by the data analytics layer. Control tasks and scheduling algorithms are also run at this point. The data will be transformed into a simple and clear form that the user can see using machine learning algorithms and various data processing approaches. Through a user interface, this layer also ensures data visualization and user interactions. Consumers may access cutting-edge energy management applications and services through the user interface. Data are first detected and gathered in the Home Access Network (HAN), then after processing, actuation and control orders are transmitted back to physical devices based on user satisfaction and energy consumption costs [52].

But by understanding data processing as a layer (Data Analytics) and combining and coordinating physical and computational aspects more, a cyber-physical architecture for Residential Energy Management is proposed.

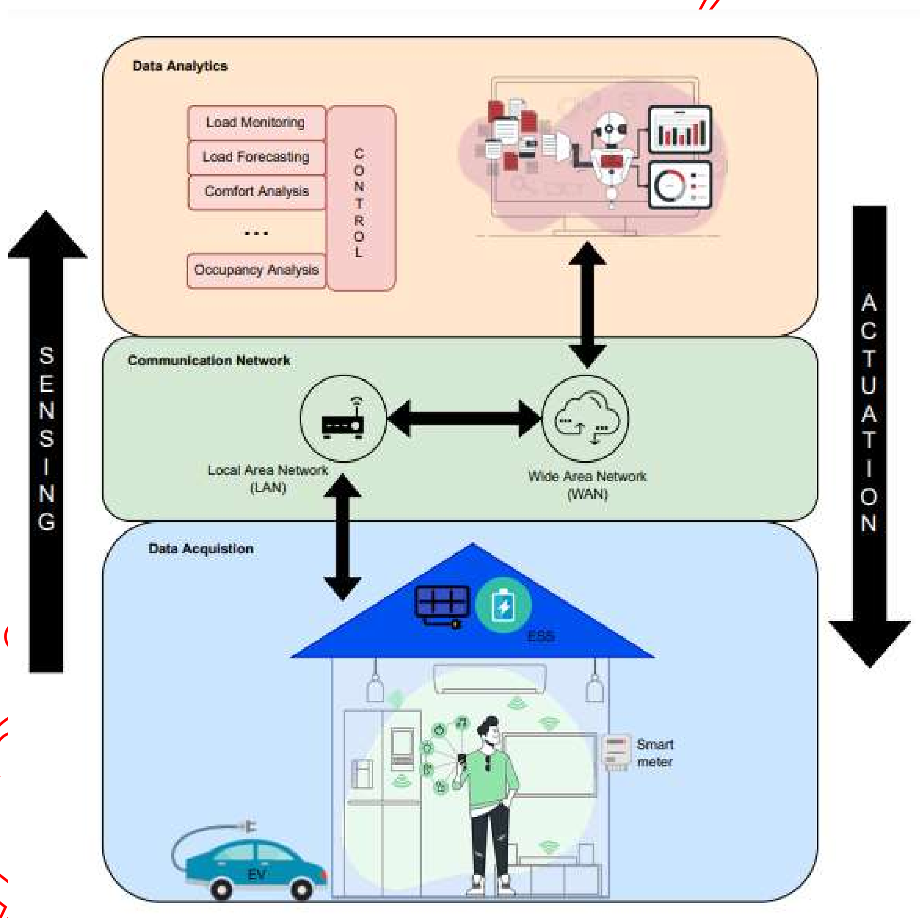

Figure 9 Residential Energy Management Stages

Data Acquisition:

In order to detect various load patterns in the following phases, the data acquisition step gets the load measurement at an appropriate rate. As well as being in charge of precision control by the actuators, this phase is carried out to have a generalized awareness of the energy supply and demand by sensors from various energy makers [53].

Therefore, two key entities work together throughout the data acquisition phase. Home appliances and metering equipment are the first. After information is gathered, measurements are forwarded to the subsequent steps for processing, as seen in Figure 10.

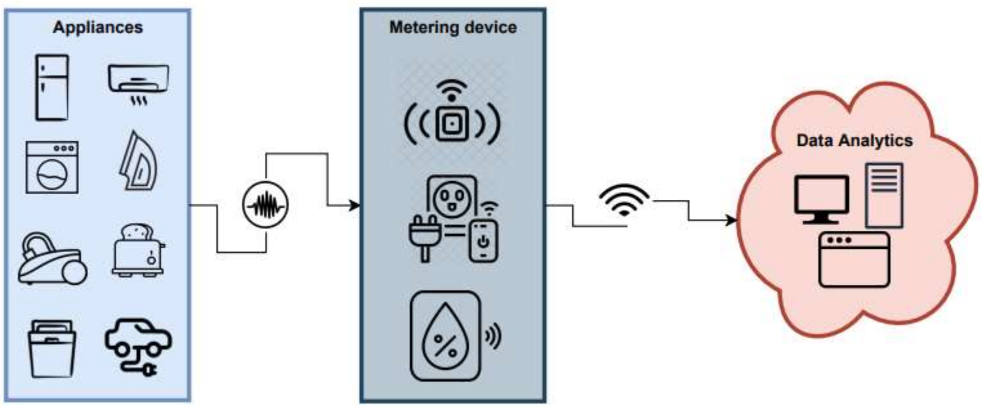

Figure 10 Data Acquisition Stage

Based on the intended usage, household appliances have been categorized in the literature. The primary categories for appliances are shown in Figure 11. According to a proposal in [54], appliances are divided into four groups for load monitoring systems. These are listed below:

- ON/OFF: Equipment with only two operational states, such as a kettle, toaster, and electric vehicles.
- Multi-state: Equipment that is represented by finite state machines (FSMs), such as heat pumps, refrigerators, and washing machines.
- Appliances having changeable power absorption properties, such as electric drills, laptops, etc., fall under the category of continuously variable.
- Permanent consumer devices: Appliances that are continuously powered on for days or weeks at a time, such as smoke detectors, TV receivers, and telephone sets.

Brainwrite xperts

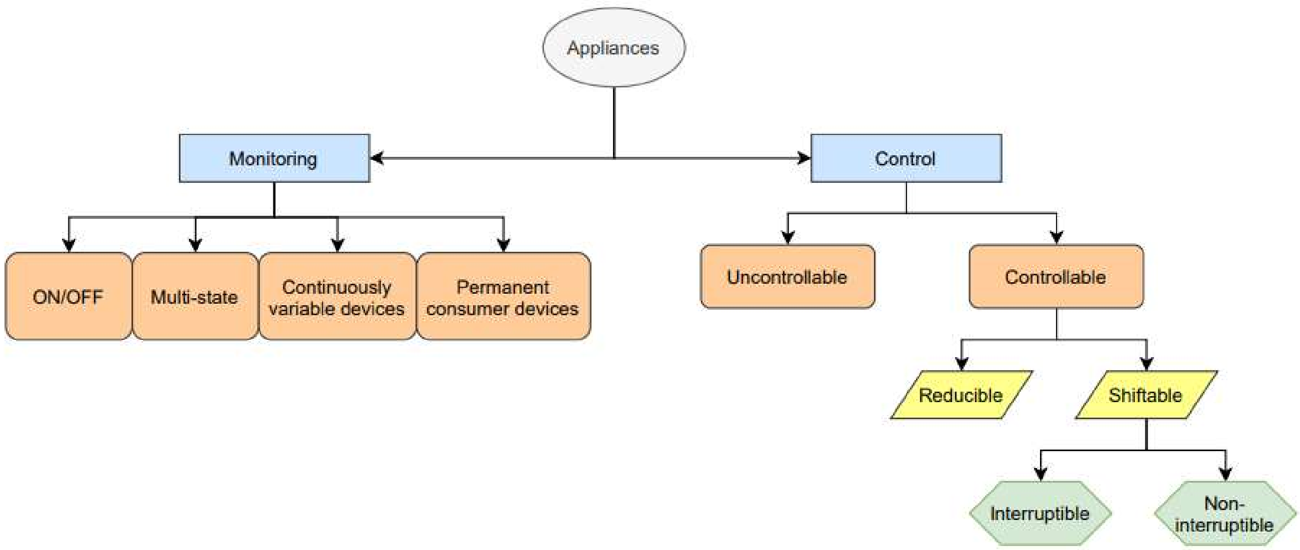

Figure 11 Appliance's Categorization

Communication Network:

For Smart Grids and home energy management, communication is essential. A communication network must be set up in order to link metering devices to an application host or service provider. The home area network is utilized within a home to enable monitoring and control over energy use. The middleware technology performs post-processing (monitoring, control, comfort analysis, occupancy, and other residential energy management applications) on the control data supplied by the metering devices and home appliances. This post-processing takes place across the communication network [55].

Due to their simplicity of installation, cost-effectiveness, and speed, wireless technologies have proven to be preferable to wired ones. A HAN schematic is shown in Figure 12. The HAN network transmits control instructions from the middleware to the energy-generating, storage, and appliance devices as well as from the utility to the appliances registered in the gateway [55]. The primary function of the home gateway is to act as a conduit between customers and the outside world. Additionally, it guarantees safe communication between the utility and customers.

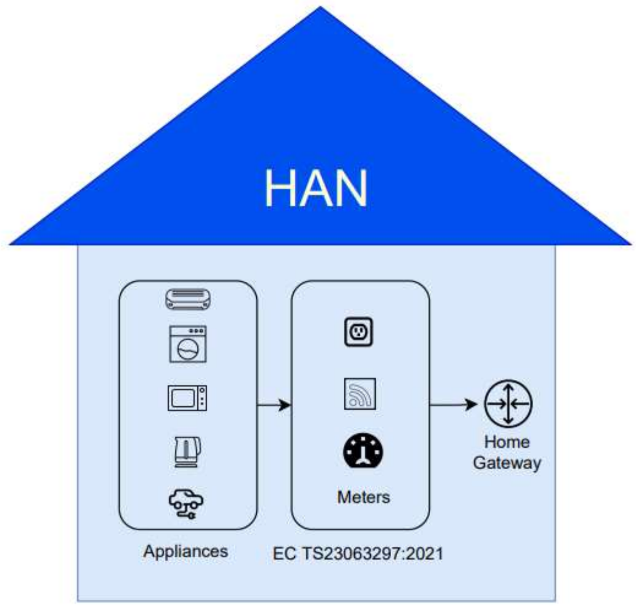

Figure 12 Home Area Network (HAN)

Considering that smart homes produce large amounts of data and smart grid applications are designed to operate in real time, including real-time pricing, demand response, and demand side management [56], the communication infrastructure must achieve low latency communication. As a potential candidate, 5G technologies stand out because of architectures based on virtualization and those specified by software that provide end-to-end services, and a multi-service ecosystem where people utilize virtualization to effectively handle a range of application needs while sharing physical infrastructure facilities. Figure 13 displays a broad picture of the smart city network architecture employing 5G technology.

Brainwrites Experts

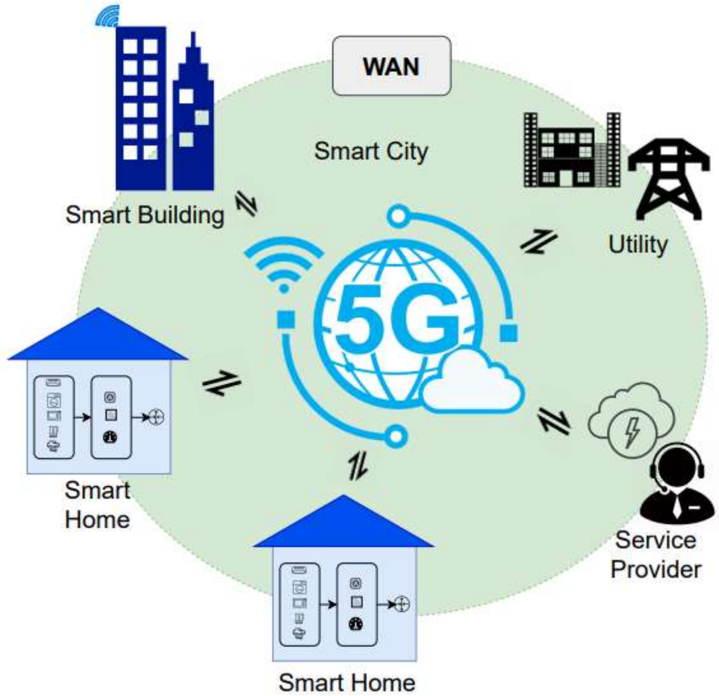

Figure 13 WAN using 5G

Data Analytics:

Making decisions, or operating the control plane, is the toughest part of the data analytics process. To optimize both computing and control techniques, this level includes a centralized processing mechanism built around cloud computing and distributed computing intelligence. AI models are used in the decision-making process to personalize local energy management strategies and adjust the system to the daily routines and lifestyles of various residents. In this manner, the data may be collected, repurposed, and visualized as needed [55]. Three key tasks must be achieved in order to construct a control plane for residential energy management:

- Gather information from various metering systems, including the HAN at the grid level.
- Provide monitoring and analysis of a household's primary loads.
- Plan the usage of various resources and equipment to maximize energy efficiency and meet user comfort and satisfaction expectations.

To develop a consumer profile that contains useful information about their behavior and other activities, load monitoring and forecasting strategies must be implemented in order to identify the

Brainwrites

main appliances in the home that consume the most electricity. The term "activities of daily living" (ADL) refers to these behaviors [57]. Cooking, washing, and preserving food are the most common tasks performed by consumers with large appliances. Monitoring and forecasting loads with ambient sensors is complementary, but it may also be beneficial for other home energy management applications, such as comfort assessments.

In the Data Analytics stage, a cyber-infrastructure analyses the data in accordance with a model and/or operating mechanism before sending instructions back to the physical devices, in accordance with the description above. According to [58], CPSs are systems that integrate sensing, communication, computation, and control functions into actual physical devices. This enables distributed sensing, dependable data transfer, and thorough information processing of the external environment. Real-time control is provided in this manner via an external loop. A HEMS may be thought of as a CPS that connects physical objects, including appliances and meters, with energy data based on this concept of a CPS. As indicated in Figure 14, measurements are gathered, processed, and delivered to the cyber-system over a communication network. Once the cyber-entity has analyzed the measurements, control directives are then issued back.

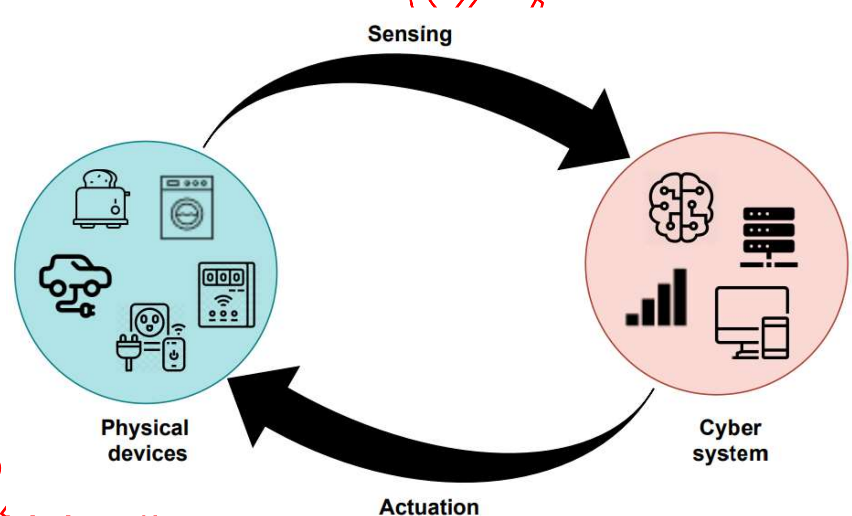

Figure 14 CPS Framework for Residential Energy Management

CHAPTER 4

4. RESULTS AND DISCUSSION

Researchers are increasingly focusing on CPS, and this ground-breaking area of study has the capacity to revolutionize how we relate to, communicate with, and work with the different complicated structures on which the physical environment is largely predicated [59]. Almost all CPS applications offer cutting-edge technology that is real enough to have a significant global influence. The application areas selected for this study heavily rely on resource efficiency, dependability, or performance improvement of home energy consumption.

An excellent resource for resolving problems with home energy management is cyber-physical systems (CPS). CPSs are systems that combine computational and physical elements in order to regulate, monitor, and improve the performance of physical systems. CPSs can be utilized in the context of home energy management to:

- Gather information on energy use: CPSs can employ sensors to gather information on the energy use of lights, appliances, and other fixtures in the home. This information may be used to spot trends in energy use and find areas where energy can be saved.
- Enhance energy usage: CPSs can enhance household energy utilization using the information gathered from sensors.
- Utilizing demand response programs, timing appliances used to correspond with off-peak hours, or adjusting the temperature are all ways to do this.
- User feedback: CPSs are able to let users know how much energy they are using. Users who want to save energy can utilize this input to better understand how much energy they are using and alter their behavior.

CPSs can be connected with other systems, such as the power grid, to offer a more comprehensive view of energy use and to enable more complex energy management methods. Prior to CPSs being extensively used, there are still a few issues that needed to be resolved as revealed by the research. These difficulties include:

BrainWrites Experts

- Cost: Implementing CPSs can be costly. This is because the system's required sensors, actuators, and software are expensive.
- Privacy: The information that CPSs acquire may be delicate. Unauthorized access must be prevented to this data.
- Security: CPSs must be protected against online threats. This is crucial for CPSs that are used to manage vital infrastructure, like the electrical grid.
- Acceptance: The users of CPSs must accept them. This means that the technologies must be simple to use and offer consumers benefits that are obvious.

4.1 CHALLENGES:

4.1.1 DATA ACQUISITION CHALLENGES

In particular, attaining energy efficiency and managing costs associated with implementation are the two biggest issues that need to be resolved in residential energy management systems. To this purpose, the research community is currently debating a uniform methodology that enables every residential energy management system application based on the gathered data. The aforementioned processes led to the identification of a number of difficulties.

The study reveals that the following difficulties are present when looking at data acquisition:

- As of operational and regulatory constraints, measures from smart meters are still non accessible in several countries.
- Due to the complexity of setup, cost, and data storage, the majority of commercial smart meters today cannot produce high-resolution data.
- Due to their expensive market prices and compatibility problems, smart appliances have not been widely used.
- High sampling rate sensors are required to meet home energy management systems criteria for large-scale applications.

4.1.2 COMMUNICATION NETWORK CHALLENGES

The following difficulties with the communication network were noted:

BrainWrites Experts

- Losses due to interference and wall intrusion are the principal difficulties to be overcome in modern houses.
- More adaptability is required, which entails using the unused spectrum.
- Smart city infrastructure must be built using technology that connects smart households and enables the use of several apps in real time. Strong candidates include the 5G and 6G technologies. The conditions for adopting these technologies at various scales (the home or the city) are still up for dispute.
- The majority of home energy management systems applications currently do not have the communication range, power utilization, or cost requirements of traditional wireless communication protocols like WiFi or Zigbee.

4.1.3 DATA ANALYTICS CHALLENGES

The problems mentioned below with data analytics were discovered:

- Concerning data resolution, precision, real-time, and the total quantity of devices to be addressed, several needs must be taken into account.
- In comparison to Intrusive Load Monitoring (ILM), Non-Intrusive Load Monitoring NILM procedures are less precise and more difficult to use in practical settings. The latter, in comparison, provides more reliability at a price. Thus, creating a hybrid method is a desirable approach to load assessment. It does, however, provide a number of difficulties that must be resolved.
- Given that appliance level enables the identification of consumption patterns of certain appliances, it can be highly helpful for residential energy management systems. Nevertheless, the scholarly community has paid less consideration to this endeavor. It is still challenging to create a unique model that predicts the consumption of various appliances.
- Although rule-based and reinforcement learning-based methods to plan and control procedures have been put forth, a thorough evaluation (via a sensitivity analysis and/or assessment of both scenarios) is required.

BrainWrites Experts

- The fact that energy data reveal users' typical patterns and behaviors, and customer confidentiality may be a barrier to the adoption of Smart Grids and home energy management systems. Consequently, cybersecurity and encryption measures must be used to grant recognized entities safe accessibility.

This study shows that, despite significant advancements over the years, research on CPS applications is still extremely fresh and in the early stages of development. There are not many publications on the topic of environmental monitoring and energy management since it does not draw as much attention from researchers. In 2016, as more scholars from diverse multi-disciplinary domains got interested in this cutting-edge line of study, studies in numerous applications of CPS began to gain significant headway [12]. However, it is anticipated that this pattern will persist and that additional groundbreaking studies will result from these applications.

CPS applications undoubtedly confront a variety of difficulties, particularly in the areas of effectiveness, security, and privacy. Due to the distinctive and inherent qualities that CPS contains, such as dynamicity, difficulty, and adaptability, it is vulnerable to several assaults on both the physical and cyber components of the system. The use of electronic communication, such as the internet, unprotected channels of communication, the utilization of commercial off-the-shelf tools, and reliance on older technologies are factors that typically play a role in CPS's fragility making them liable for threats and attacks [60]. The total number of publications on security in relation to energy CPS research is depicted in Figure 15.

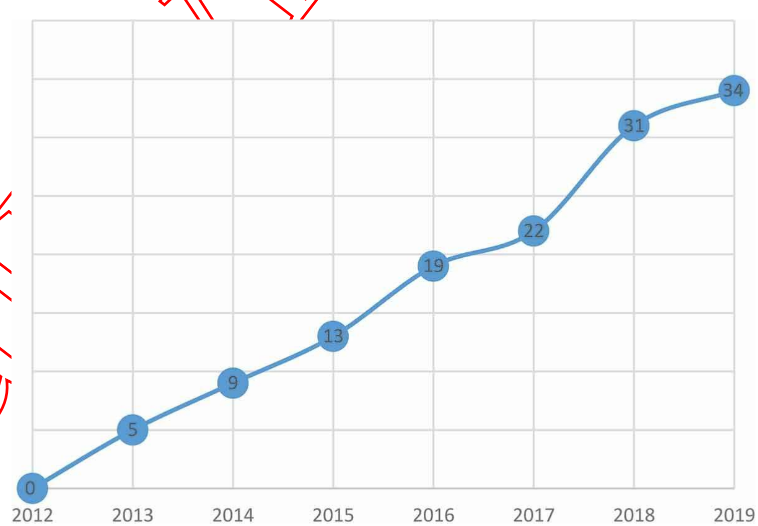

Figure 15 publications on security issues in Energy CPS

BrainiesExperts

The quantity of research being done in this area to tackle security is regarded to be steadily rising. As safety in large-scale systems-related challenges are addressed, research effort has increased significantly since 2017.

According to the literature review technique used in this study, it was found that CPS is now outpacing other related technologies including Machine-2-Machine, the Internet of Things, big data, storage, and cloud.

Brainwrites Experts

BrainWrites Experts

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

The primary research findings are summarized in this chapter, along with a few suggestions for further research.

5.1 CONCLUSION

The escalating need for electricity in recent decades has given rise to smart grids, which intend to revolutionize the way power is generated, controlled, and used. The majority of electricity providers have realized the necessity of making the switch from a traditional grid to a smart grid or, even more significantly, to the Infrastructural Internet of Things or smart cities. In terms of technology, a smart grid is a power system that uses information and communications technology (ICT) more often. To enhance the quality of service and preserve the supply of energy, the ICT infrastructure gathers, distributes, analyses, and reacts to every component behavior.

The use of Cyber-physical systems (CPS) in smart homes energy management is increasing daily. An excellent study opportunity to investigate communication, computing, and regulating of physical objects utilizing real-time processing and analytics is provided by the smart home outfitted with sensors and electrical gadgets as a CPS. Clearly, CPS offers a variety of capabilities for smart homes specifically in the power resilience domain. Additionally, research has shown that a sizeable portion of the energy used in homes happens at night and is mostly required to power networking equipment. Designing a cyber-physical energy system that optimizes energy consumption by scheduling and executing sleep modes for equipment in line with real-time pricing transfers can reduce the amount of greenhouse gas emissions.

In other words, the smart grid intends to handle a number of components at the user end, including smart meters, electric vehicles (EVs), and energy storage systems (ESS). Resilience of residential energy consumption enables families to efficiently centralize the service administration and offer users functions for the internal and external interchange of data, which is why a successful residential energy management technique is necessary. In that regard, the system must carry out two key tasks: arranging the best possible energy usage for home appliances and real-time energy monitoring of customers using meters and smart devices. With the incorporation of sensors, actuators, and measuring devices, data-driven strategies based on different Machine Learning (ML) techniques and Internet of Things (IoT) technologies increasingly stand out as an appealing way of solving the problems of observing, safeguarding, and regulating. The advantages of the development of such systems may be seen in a wide range of industries, from commercial services to distant healthcare.

This study provides an overview of cutting-edge ideas and methods for domestic energy management. We suggested a three-stage cyber-physical methodology that included data acquisition, communication networks, and data analytics. A comprehensive analysis of the pertinent literature revealed a variety of technologies and methods that constitute secure alternatives for intelligent metering devices in the data-gathering phase. Various technologies were examined in the context of HAN and WAN for the communication phase. Famous wireless data transfer protocols like WiFi, Zigbee, and LoRa provide dependable communication between utilities and metering equipment. Pertinent literature has been examined in relation to data analytics, emphasizing this step as the cyber component of the resilience of residential energy consumption.

This paper suggested a three-layered design for residential energy management on the basis of the study done. The primary equipment in a household might be monitored via the suggested cyber-physical platform.

5.2 RECOMMENDATIONS

This study was conducted utilizing a systematic literature review method that allowed us to seek, analyze, evaluate, investigate, and categorize already published, carefully chosen articles in the literature. We were also able to determine the relationship and connection between these papers, which allowed us to make an accurate conclusion about their material. To help researchers discover fresh techniques in this field of study, a comprehensive evaluation of articles was conducted using information from several sources. Based on our findings, it is clear that interest in contemporary ideas and technology in this field is increasing tremendously, particularly in recent years, as seen by the number of publications in this field.

In order to increase the cyber resilience of their energy systems, several nations and businesses are establishing and putting into practice regulations and initiatives. Numerous major areas of action

BrainWrites Experts

can serve as the foundation for attaining more suitable electrical safety frameworks in the years to come, even if various scenarios necessitate unique methods. These include institutionalizing accountability and incentives, identifying risks, controlling and reducing risks, tracking progress, and resolving disruptions. Following are the recommendations to create a robust energy system and strike a balance between affordability, energy security, and environmental sustainability:

- Give energy efficiency solutions first priority and apply them as much as possible to reduce the amount of primary energy used while still satisfying social and economic demands.
- Automate the power system and benefit from rising customer digital literacy to seize the tremendous value chain optimization potential.
- Quicken fuel switching to reduce the environmental impact of end-use energy and, when possible, switch out carbon-intensive fuels for low- and zero-carbon alternatives.
- Increase the use of energy from renewable sources, nuclear power, and upgraded fossil fuels with carbon collection, utilization, and storage to hasten the adoption of low- and zero-carbon technologies.

Researchers who enter this study field should take into consideration the possibility that the combination and merging of various research fields might result in further technological improvement and breakthroughs in the future. The impact of these technologies on CPS applications and the underlying problems with interoperability, dependability, and safety must also be studied, though. Additionally, for future applications, CPS will play a very significant and prominent part in China's "Made in China 2025" and Germany's "Industry 4.0" initiatives, as well as other CPS-related projects.

However, further extensive research is required to support and advance our understanding of the subject. We advise that the suggested measurements mentioned in this paper be put into practice in the following stages, along with monitoring the behavior of systems, and cyber risks and iteratively adding more metrics for the various phases.

BrainWrites Experts

REFERENCES

[1] S. Lee and D.-H. Choi, "Energy Management of Smart Home with Home Appliances, Energy Storage System and Electric Vehicle: A Hierarchical Deep Reinforcement Learning Approach," *Sensors*, vol. 20, no. 7, p. 2157, Apr. 2020, doi: https://doi.org/10.3390/s20072157.

[2] D. Ahuja and M. Tatsutani, "Sustainable energy for developing countries," *S.A.P.I.EN.S. Surveys and Perspectives Integrating Environment and Society*, vol. 2, no. 2.1, Apr. 2009, Available: https://journals.openedition.org/sapiens/823

[3] M. Kamran, "Conventional Power Plant - an overview | ScienceDirect Topics," *www.sciencedirect.com*, 2023. https://www.sciencedirect.com/topics/engineering/conventional-power-plant

[4] R. Liaqat, I. A. Sajjad, M. Waseem, and H. H. Alhelou, "Appliance Level Energy Characterization of Residential Electricity Demand: Prospects, Challenges and Recommendations," *IEEE Access*, vol. 9, pp. 148676–148697, 2021, doi: https://doi.org/10.1109/access.2021.3123196.

[5] P. Palensky and D. Dietrich, "Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 3, pp. 381–388, Aug. 2011, doi: https://doi.org/10.1109/tii.2011.2158841.

[6] F. Kühnlenz, P. H. J. Nardelli, and H. Alves, "Demand Control Management in Microgrids: The Impact of Different Policies and Communication Network Topologies," *IEEE Systems Journal*, vol. 12, no. 4, pp. 3577–3584, Dec. 2018, doi: https://doi.org/10.1109/JSYST.2018.2808940.

[7] B. Ramanathan and V. Vittal, "A Framework for Evaluation of Advanced Direct Load Control With Minimum Disruption," *IEEE Transactions on Power Systems*, vol. 23, no. 4, pp. 1681–1688, Nov. 2008, doi: https://doi.org/10.1109/tpwrs.2008.2004732.

[8] M. Imran Malik, A. Ibrahim, P. Hannay, and L. F. Sikos, "Developing Resilient Cyber-Physical Systems: A Review of State-of-the-Art Malware Detection Approaches, Gaps, and Future Directions," *Computers*, vol. 12, no. 4, pp. 79–79, Apr. 2023, doi: https://doi.org/10.3390/computers12040079.

BrainWrites Experts

[9] P. Wood, "Purdue e-Pubs Improving the resilience of cyber-physical systems under strategic adversaries," 2016. Accessed: Aug. 28, 2023. [Online]. Available: https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2075&context=open_access_dissertations

[10] K. R, "Energy Optimization of Residential Energy Management in Micro Grid using Cyber Physical Controller," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 2, pp. 1166–1171, Apr. 2020, doi: https://doi.org/10.30534/ijatcse/2020/41922020.

[11] Stamatis Karnouskos, "Smart houses in the smart grid and the search for value-added services in the cloud of things era," *International Conference on Industrial Technology*, Apr. 2013, doi: https://doi.org/10.1109/icit.2013.6505988.

[12] Muzaffar Hamzah *et al.*, "Distributed Control of Cyber Physical System on Various Domains: A Critical Review," *Intelligent Systems and Cybersecurity*, vol. 11, no. 4, pp. 208–208, Apr. 2023, doi: https://doi.org/10.3390/systems11040208.

[13] C. Giudicianni, M. Herrera, A. di Nardo, K. Adeyeye, and H. M. Ramos, "Overview of Energy Management and Leakage Control Systems for Smart Water Grids and Digital Water," *Modelling*, vol. 1, no. 2, pp. 134–155, Oct. 2020, doi: https://doi.org/10.3390/modelling1020009.

[14] M. A. Islam, M. Hasanuzzaman, N. A. Rahim, A. Nahar, and M. Hosenuzzaman, "Global Renewable Energy-Based Electricity Generation and Smart Grid System for Energy Security," *The Scientific World Journal*, vol. 2014, 2014, doi: https://doi.org/10.1155/2014/197136.

[15] H. Hasselqvist, S. Renström, H. Strömberg, and M. Håkansson, "Household energy resilience: Shifting perspectives to reveal opportunities for renewable energy futures in affluent contexts," *Energy Research & Social Science*, vol. 88, p. 102498, Jun. 2022, doi: https://doi.org/10.1016/j.erss.2022.102498.

[16] B. Li, R. Lu, and G. Xiao, *Detection of False Data Injection Attacks in Smart Grid Cyber-Physical Systems*. 2020, pp. 1–22. doi: https://doi.org/10.1007/978-3-030-58672-0_1.

[17] M. N. O. Sadiku, Y. Wang, S. Cui, and S. M. Musa, "Cyber-Physical Systems: A Literature Review," *European Scientific Journal, ESJ*, vol. 13, no. 36, p. 52, 2017, Accessed: Aug. 30, 2023.

BrainWrites Experts

[Online].Available:
https://www.academia.edu/35649106/Cyber_Physical_Systems_A_Literature_Review

[18] NSF, "NSF Workshop on Cyber-Physical Systems | CPS-VO," *cps-vo.org*, 2006. https://cps-vo.org/node/179 (accessed Aug. 30, 2023).

[19] B. Krogh, M. Ilic , and S. Sastry, "National Workshop on Beyond SCADA: Networked Embedded Control for Cyber-Physical Systems (NEC4CPS): Research Strategies and Roadmap," 2007. Available: https://cps-vo.org/NEC4CPS-report

[20] G. W. Bush, "Leadership Under Challenge: Information Technology R&D in a Competitive World," 2007. Accessed: Aug. 30, 2023. [Online]. Available: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-07-nitrd-review.pdf

[21] C. Greer, M. Burns, D. Wollman, and E. Griffor, "Cyber-physical Systems and Internet of Things," *NIST Special Publication 1900-202*, Mar. 2019, doi: https://doi.org/10.6028/nist.sp.1900-202.

[22] R. Helal, A. Seghiri, and F. Belala, "An Integrated Approach to Formal Analyze Cyber Physical Systems," 2022. Accessed: Aug. 30, 2023. [Online]. Available: https://ceur-ws.org/Vol-3333/Paper9.pdf

[23] G. Wu *et al.*, "Understanding resilience," *Frontiers in Behavioral Neuroscience*, vol. 7, no. 10, 2013, doi: https://doi.org/10.3389/fnbeh.2013.00010.

[24] M. Panteli and P. Mancarella, "The Grid: Stronger, Bigger, Smarter?: Presenting a Conceptual Framework of Power System Resilience," *IEEE Power and Energy Magazine*, vol. 13, no. 3, pp. 58–66, May 2015, doi: https://doi.org/10.1109/mpe.2015.2397334.

[25] UNECE, "Building Resilient Energy Systems," 2023.

[26] Union of Concerned Scientists, "Benefits of Renewable Energy Use," *Union of Concerned Scientists*, Dec. 20, 2017. https://www.ucsusa.org/resources/benefits-renewable-energy-use

BrainWrites Experts

[27] L. Jones, E. Samman, and P. Vinck, "Subjective measures of household resilience to climate variability and change: insights from a nationally representative survey of Tanzania," *Ecology and Society*, vol. 23, no. 1, 2018, doi: https://doi.org/10.5751/es-09840-230109.

[28] P. Franco, J. M. Martínez, Y.-C. Kim, and M. A. Ahmed, "A Cyber-Physical Approach for Residential Energy Management: Current State and Future Directions," *Sustainability*, vol. 14, no. 8, p. 4639, Apr. 2022, doi: https://doi.org/10.3390/su14084639.

[29] S. Stout, N. Lee, S. Cox, and J. Elsworth, "POWER SECTOR RESILIENCE PLANNING GUIDEBOOK," 2019. Available: https://www.nrel.gov/docs/fy19osti/73489.pdf

[30] M. Ghiasi, Z. Wang, T. Niknam, M. Dehghani, and Hamid Reza Ansari, "Cyber-Physical Security in Smart Power Systems from a Resilience Perspective: Concepts and Possible Solutions," pp. 67–89, Jan. 2023, doi: https://doi.org/10.1007/978-3-031-20360-2_3.

[31] M. de Castro Tomé, P. H. J. Nardelli, H. M. Hussain, S. Wahid, and A. Narayanan, "A Cyber-Physical Residential Energy Management System via Virtualized Packets," *Energies*, vol. 13, no. 3, p. 699, Jan. 2020, doi: https://doi.org/10.3390/en13030699.

[32] E. F. Orumwense and K. Abo-Al-Ez, "A systematic review to aligning research paths: Energy cyber-physical systems," *Cogent Engineering*, vol. 6, no. 1, p. 1700738, Jan. 2019, doi: https://doi.org/10.1080/23311916.2019.1700738.

[33] B. N. Green, C. D. Johnson, and A. Adams, "Writing narrative literature reviews for peer-reviewed journals: secrets of the trade," *Journal of Chiropractic Medicine*, vol. 5, no. 3, pp. 101–117, Sep. 2006, doi: https://doi.org/10.1016/s0899-3467(07)60142-6.

[34] G. Cicceri, G. Tricomi, L. D'Agati, F. Longo, G. Merlino, and A. Puliafito, "A Deep Learning-Driven Self-Conscious Distributed Cyber-Physical System for Renewable Energy Communities," *Sensors*, vol. 23, no. 9, p. 4549, May 2023, doi: https://doi.org/10.3390/s23094549.

[35] Y. Allahvirdizadeh, M. P. Moghaddam, and H. Shayanfar, "A survey on cloud computing in energy management of the smart grids," *International Transactions on Electrical Energy Systems*, vol. 29, no. 10, Jul. 2019, doi: https://doi.org/10.1002/2050-7038.12094.

Brainwrites Experts

[36] P. Samadi, H. Mohsenian-Rad, R. Schober, and V. W. S. Wong, "Advanced Demand Side Management for the Future Smart Grid Using Mechanism Design," *IEEE Transactions on Smart Grid*, vol. 3, no. 3, pp. 1170–1180, Sep. 2012, doi: https://doi.org/10.1109/tsg.2012.2203341.

[37] J. Guiochet, M. Machin, and H. Waeselynck, "Safety-critical advanced robots: A survey," *Robotics and Autonomous Systems*, vol. 94, pp. 43–52, Aug. 2017, doi: https://doi.org/10.1016/j.robot.2017.04.004.

[38] M. Törngren and U. Sellgren, "Complexity Challenges in Development of Cyber-Physical Systems," *Lecture Notes in Computer Science*, pp. 478–503, 2018, doi: https://doi.org/10.1007/978-3-319-95246-8_27.

[39] C. Konstantinou, "Cyber-Physical Systems Security Education Through Hands-on Lab Exercises," *IEEE Design & Test*, pp. 1–1, 2020, doi: https://doi.org/10.1109/mdat.2020.3005365.

[40] European Parliamentary Research Service, "Ethical Aspects of Cyber-Physical Systems Scientific Foresight study STUDY Science and Technology Options Assessment," 2016. Available: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/563501/EPRS_STU%282016%29563501_EN.pdf

[41] R. Ferrari, "(PDF) Writing narrative style literature reviews," *ResearchGate*, 2015. https://www.researchgate.net/publication/288039333_Writing_narrative_style_literature_reviews

[42] M. Juntunen and M. Lehenkari, "A narrative literature review process for an academic business research thesis," *Studies in Higher Education*, vol. 46, no. 2, pp. 1–13, Jun. 2019, doi: https://doi.org/10.1080/03075079.2019.1630813.

[43] F. Middleton, "Reliability vs validity in research," *Scribbr*, Jul. 03, 2019. https://www.scribbr.com/methodology/reliability-vs-validity/

[44] L. Leung, "Validity, reliability, and Generalizability in Qualitative Research," *Journal of Family Medicine and Primary Care*, vol. 4, no. 3, pp. 324–327, 2015, Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4535087/

BrainWrites Experts

[45] S. Colabianchi, F. Costantino, G. Di Gravio, F. Nonino, and R. Patriarca, “Discussing resilience in the context of cyber physical systems,” *Computers & Industrial Engineering*, vol. 160, p. 107534, Oct. 2021, doi: https://doi.org/10.1016/j.cie.2021.107534.

[46] Y. Ashibani and Q. H. Mahmoud, “Cyber physical systems security: Analysis, challenges and solutions,” *Computers & Security*, vol. 68, pp. 81–97, Jul. 2017, doi: https://doi.org/10.1016/j.cose.2017.04.005.

[47] J.-P. A. Yaacoub, O. Salman, H. N. Noura, N. Kaaniche, A. Chehab, and M. Malli, “Cyber-physical systems security: Limitations, issues and future trends,” *Microprocessors and Microsystems*, vol. 77, p. 103201, Sep. 2020, doi: https://doi.org/10.1016/j.micpro.2020.103201.

[48] D. Koutras, G. Stergiopoulos, T. Dasaklis, P. Kotzanikolaou, D. Glynos, and C. Douligeris, “Security in IoMT Communications: A Survey,” *Sensors*, vol. 20, no. 17, p. 4828, Jan. 2020, doi: https://doi.org/10.3390/s20174828.

[49] N. Verma, S. Singh, and D. Prasad, “A Review on existing IoT Architecture and Communication Protocols used in Healthcare Monitoring System,” *Journal of The Institution of Engineers (India): Series B*, Jun. 2021, doi: https://doi.org/10.1007/s40031-021-00632-3.

[50] S. De, Y. Zhou, I. Larizgoitia Abad, and K. Moessner, “Cyber–Physical–Social Frameworks for Urban Big Data Systems: A Survey,” *Applied Sciences*, vol. 7, no. 10, p. 1017, Oct. 2017, doi: https://doi.org/10.3390/app7101017.

[51] S. Panda *et al.*, “Residential Demand Side Management model, optimization and future perspective: A review,” *Energy Reports*, vol. 8, pp. 3727–3766, Nov. 2022, doi: https://doi.org/10.1016/j.egyr.2022.02.300.

[52] J. Wan, H. Yan, Q. Liu, K. Zhou, R. Lu, and D. Li, “Enabling cyber-physical systems with machine-to-machine technologies,” *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 13, no. 3/4, p. 187, 2013, doi: https://doi.org/10.1504/ijahuc.2013.055454.

[53] Y. Zhang, T. Huang, and E. F. Bompard, “Big data analytics in smart grids: a review,” *Energy Informatics*, vol. 1, no. 1, Aug. 2018, doi: https://doi.org/10.1186/s42162-018-0007-5.

[54] G. W. Hart, “Nonintrusive appliance load monitoring,” *Proceedings of the IEEE*, vol. 80, no. 12, pp. 1870–1891, 1992, doi: https://doi.org/10.1109/5.192069.

BrainWrites Experts

[55] Y. Liu, X. Yang, W. Wen, and M. Xia, “Smarter Grid in the 5G Era: A Framework Integrating Power Internet of Things With a Cyber Physical System,” *Frontiers in Communications and Networks*, vol. 2, Jun. 2021, doi: https://doi.org/10.3389/frcmn.2021.689590.

[56] F. Bouhafs, M. Mackay, and M. Merabti, “Links to the Future: Communication Requirements and Challenges in the Smart Grid,” *IEEE Power and Energy Magazine*, vol. 10, no. 1, pp. 24–32, Jan. 2012, doi: https://doi.org/10.1109/mpe.2011.943134.

[57] P. Franco, J. M. Martinez, Y.-C. Kim, and M. A. Ahmed, “IoT Based Approach for Load Monitoring and Activity Recognition in Smart Homes,” *IEEE Access*, vol. 9, pp. 45325–45339, 2021, doi: https://doi.org/10.1109/access.2021.3067029.

[58] F. Tao, Q. Qi, L. Wang, and A. Y. C. Nee, “Digital Twins and Cyber–Physical Systems toward Smart Manufacturing and Industry 4.0: Correlation and Comparison,” *Engineering*, vol. 5, no. 4, pp. 653–661, Aug. 2019, doi: https://doi.org/10.1016/j.eng.2019.01.014.

[59] S. Kim and K.-J. Park, “A Survey on Machine-Learning Based Security Design for Cyber-Physical Systems,” *Applied Sciences*, vol. 11, no. 12, p. 5458, Jun. 2021, doi: https://doi.org/10.3390/app11125458.

[60] V. Gunes, S. Peter, T. Givargis, and F. Vahid, “A Survey on Concepts, Applications, and Challenges in Cyber-Physical Systems,” *KSII Transactions on Internet and Information Systems*, vol. 8, no. 12, pp. 4242–4268, Dec. 2014, Available: https://www.itiis.org/digital-library/manuscript/894

BrainwritesExperts